METHOD OF POLING FERROELECTRIC MATERIALS

The invention relates to a method of poling a sample of ferroelectric material, comprising a plurality of ferroelectric layers arranged in a stack, so as to induce bulk piezoelectricity. In particular, but not exclusively, the invention relates to a method of poling multilayer ferroelectric samples of the type suitable for use in piezoelectric actuators for fuel injection systems for internal combustion engines.

In a piezoelectric crystal, mechanical strain or force is generated when an electric field is applied across opposite faces of the crystal. When the applied field is removed, the crystal structure will return to its original shape. Inorganic materials are only naturally piezoelectric in their single crystal form, whereas in a polycrystalline sample the individual crystallites are usually randomly oriented following manufacture. Although the crystallites individually exhibit piezoelectric coupling, the lack of overall preferred orientation means a piezoelectric effect is not apparent in the bulk material. Before such polycrystalline samples can be used in the manufacture of actuators, for example, it is therefore necessary to pole the material to align the dipoles, so as to give a crystal lattice structure with a preferred axis and direction.

In a ferroelectric crystal, permanent crystallographic reorientation can be induced by applying a sufficiently large electric field across opposite faces of the crystal (i.e. poling the crystal). Ferroelectric poling is illustrated in Figure 1, which shows electric dipole moments 10 in a ferroelectric polycrystalline sample 12 (a) before poling (b) during poling and (c) after poling. The minimum electric field strength necessary to cause permanent crystallographic realignment, and dipole reorientation, is referred to as the "coercive" field strength. Once the coercive field strength is exceeded, the ferroelectric dipoles 10 become aligned (Figure 1(c)). The permanent crystallographic reorientation that takes place during poling causes a small but significant change in sample shape, comprising an elongation

material adjacent to the external electrodes 20a, 20b. This gives rise to a ferroelectric strain discontinuity between the regions of poled and unpoled material, placing the unpoled material in tension and the poled material in compression. As a result, the poled material has a tendency to fracture and the unpoled material tends to clamp the adjacent poled material, thereby causing the multilayer structure to distort.

Secondly, in order to avoid undesirable "surface flashover" effects, which arise if the internal electrodes 18a, 18b meet the free surface of the sample, the internal electrodes 18a, 18b are buried by terminating them short of the free surface. Again, this leads to a region of the ceramic that remains unpoled (i.e. a region immediately below the free surface, typically having a width of a few hundred microns), resulting in ferroelectric strain discontinuities between poled and unpoled regions.

One known way of preventing surface flashover whilst avoiding the use of buried internal electrodes is to apply some form of passivation to the surface of the sample, such as a polymer encapsulation with relatively high dielectric strength. This provides a partial solution, but an unpoled region of the ceramic remains behind the external electrodes 20a, 20b to isolate the two sets of internal electrodes 18a and 18b. The outermost ones of the piezoelectric layers 40a, 40b that define the end faces of the multilayer structure 14 do not lie between two internal electrodes, and so are not exposed to the coercive field during poling. The outermost piezoelectric layers 40a, 40b therefore remain unpoled.

It is known to apply a poling voltage to a multilayer ferroelectric block in order to induce bulk piezoelectricity in the block. Following poling, the block is then divided or cut into individual samples suitable for use in a particular application, a piezoelectric actuator in a fuel injector, for example.

It is an object of the present invention to provide a method of poling a sample of ferroelectric material which removes or alleviates the aforementioned problems.

According to the present invention, there is provided a method of poling a. ferroelectric sample of the type suitable for use in an actuator for an injection arrangement, the method comprising:

providing a sample of ferroelectric material having first and second opposing end faces, first and second opposing side faces, and a stack of ferroelectric layers, wherein adjacent layers are separated from one another by one of a plurality of internal electrodes arranged substantially parallel to the end faces of the sample,

applying a primary external electrode arrangement to the first and second end faces of the sample,

applying a primary poling voltage to the primary external electrode arrangement so as to polarise substantially the entire ferroelectric sample along a single, first polarisation axis in a first polarisation direction,

applying a secondary external electrode arrangement to the side faces of the sample,

applying a secondary poling voltage to the secondary electrode arrangement so as to polarise alternate ones of the ferroelectric layers along substantially the first polarisation axis in the first polarisation direction and the others of the ferroelectric layers are polarised along a second, oppositely directed polarisation axis,

such that substantially the entire sample is polarised whilst substantially avoiding

CLAIMS

1. A method of poling a ferroelectric sample (14) of the type suitable for use in an actuator for an injection arrangement comprising:

providing a sample of ferroelectric material having first and second opposing end faces (23), first and second opposing side faces (21), and a stack of ferroelectric layers (16), wherein adjacent layers (16) are separated from one another by internal electrodes (18a, 18b) arranged substantially parallel to the end faces (23) of the sample (14),

applying a primary external electrode arrangement to the first and second end faces (23) of the sample,

applying a primary poling voltage to the primary external electrode arrangement so as to polarise substantially the entire ferroelectric sample (14) along a single, first polarisation axis in a first polarisation direction.

applying a secondary external electrode arrangement to the side faces of the sample (14),

applying a secondary poling voltage to the secondary external electrode arrangement so as to polarise alternate ones of the ferroelectric layers (16) along substantially the first polarisation axis in the first polarisation direction and the others of the ferroelectric layers (16) are polarised along a second, oppositely directed polarisation axis,

thereby to polarise substantially the entire sample (14) and avoiding discontinuities in ferroelectric strain throughout the sample (14),